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Computational Fluid Dynamics for Hot Water Layer in Pool-type Research Reactor

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1. Introduction

The hot water layer system (HWLS) operates as a distinct subsystem in open pool-type research reactors [1,2,3]. Its primary function involves releasing high-temperature water into the reactor pool, creating a high-temperature layer to prevent radioactive materials generated in the reactor core from ascending to the upper section. Consequently, the hot water layer system plays a crucial role in minimizing radiation levels on the pool surface. This research provides a numerical analysis procedure for an open pool-type research reactor. Additionally, this paper presents simulation results under steady-state conditions to confirm the formation of the hot water layer.

2. Methods and Results

In this section, the overall procedure for an open pool-type research reactor is described. The numerical analysis is conducted using the computational fluid dynamics (CFD) code, ANSYS FLUENT, to simulate the research reactor

2.1 Pool-type Research Reactor

To simulate the flow in the reactor pool, a three-dimensional geometric model of an open-type tank was created using ANSYS Space Claim. It is crucial to model all structures that influence the velocity and temperature fields in the reactor pool. The HWLS supplies high-temperature water to the upper part of the reactor pool, and mass is balanced through the outlet pipes. The geometry of the inlet and outlet pipes was also modeled. To maintain a reasonable cost for the simulation, negligible gaps or components should be excluded in the modeling

2.2 Meshing

Assuming that the research reactor's pool size exceeds 10 meters, a basic mesh size of 15 cm was assigned to the entire region (Fig. 1). The mesh type is polyhedral, and prism layers are applied to the boundaries and walls. To prevent reverse flow, a finer mesh was implemented at the inlet and outlet, where the flow enters and exits, respectively.

The hot water layer system results in thermal stratification in the upper part, where a steep temperature gradient is expected. Therefore, a finer mesh is required to capture the temperature distribution accurately and reduce computational errors

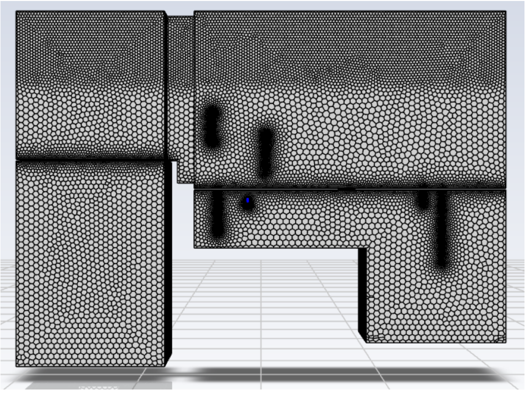

Fig. 1. Mesh scene of open pool-type research reactor applied with coarse mesh(left) and fine mesh(right)

2.3 Boundary Conditions

Before conducting the computational analysis, the setup for boundary conditions must be completed. The inlet of the hot water layer system provides high-temperature water with a designed flow rate. The wall of reactor pool is considered an adiabatic wall, with no heat transfer to the ambient environment being taken into account. The top surface of the reactor pool is set as a slip condition since it represents the interface between water and air. The inlet temperature is assumed to be 55℃, and the outlet pipe of the HWLS is assigned as the mass flow outlet

2.3 Physics and Solver

The flow regime in the reactor pool depends on overall operating conditions, such as inlet velocity, pool size, and fluid characteristics. In this simulation, the k-epsilon model was applied to the simulation domain. The working principle of the HWLS is to induce thermal stratification driven by density differences. Therefore, the Boussinesq equation was used for water density.

To solve the pressure and velocity fields, the SIMPLE (Semi-implicit method for pressure-linked equations) solver was employed, as it is quicker than the coupled method, which solves pressure and velocity fields simultaneously, leading to slower convergence. Considering that the second-order upwind scheme can provide more accurate results, it was used for the momentum and energy equations

To achieve solution convergence, under-relaxation factors (UDFs) must be appropriately adjusted. The UDFs for momentum, turbulent kinetic energy, turbulent dissipation rate, and turbulent viscosity were set below 0.5, while the UDF for energy ranged between 0.5 to 1.

The heater capacity of the HWLS was determined by calculating the enthalpy difference between the inlet and outlet pipes of the HWLS. The simulation continued until the heater capacity converged

2.4 Results and Conclusion

The heater capacity of the HWLS was monitored to assess solution convergence. In Fig 2, the heater capacity decreases with each iteration and eventually converges to a certain value, indicating that the solution has stabilized and is not significantly changing.

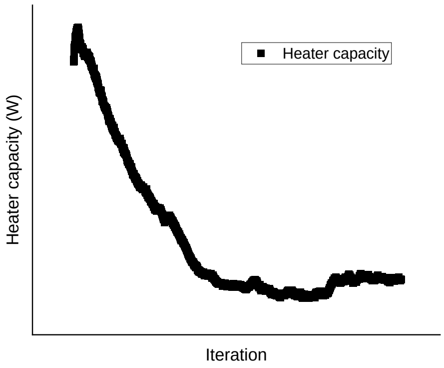

Fig. 2. Heater capacity of HWLS over iteration when the inlet temperature of the HWLS is constant

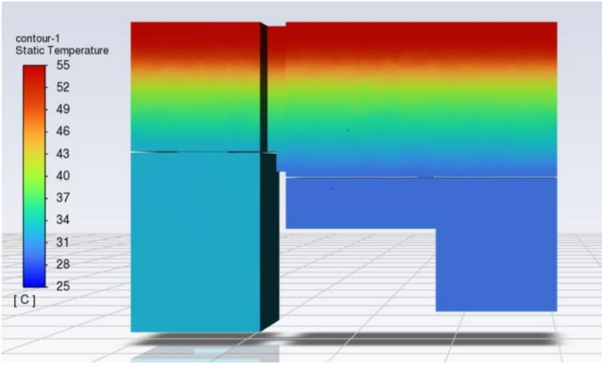

Fig. 3. Pool temperature distribution of the reactor pool

The reactor pool temperature is illustrated in Fig. 3. Due to the lower density of high-temperature water compared to low-temperature water, clear thermal stratification is observed. This physical phenomenon effectively hinders the movement of radioactive materials, aligning with the intended purpose. The temperature distribution is influenced by both the reactor operating conditions and the arrangement of inner structures

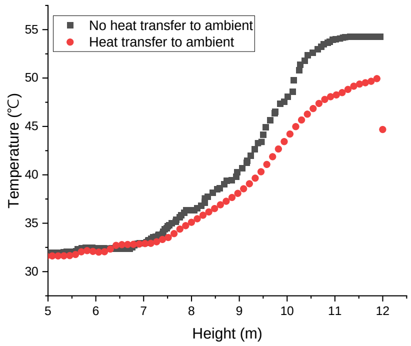

Fig. 4. Temperature distribution in the reactor pool

Fig. 4 highlights the significance of heat transfer to the ambient environment. All simulation parameters were consistent between the two cases, except for heat transfer on the pool surface. When the ambient temperature is 20 ℃, a sudden temperature drop is expected, resulting in an overall temperature slightly lower than in cases where heat transfer to the ambient was not considered.

3. Conclusions

This research numerically simulated an open pool-type research reactor using ANSYS FLUENT, taking into account influential structures within the reactor pool. The simulation included the operation of the Hot Water Layer System (HWLS), which resulted in the stable formation of a hot water layer through high-temperature water discharge, maintained by the density difference between hot and cold water.

Heat transfer to the ambient significantly influenced the temperature distribution inside the reactor pool. An ambient temperature of 20 ℃ caused a lowering of the pool temperature, resulting in a more even temperature distribution. Through the analysis procedure and results, this research has provided insights into understanding the functionality of the HWLS in open-pool type research reactors. Furthermore, it suggests the necessity for further research to define the thickness of the hot water layer.

ACKNOWLEDGEMENT

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